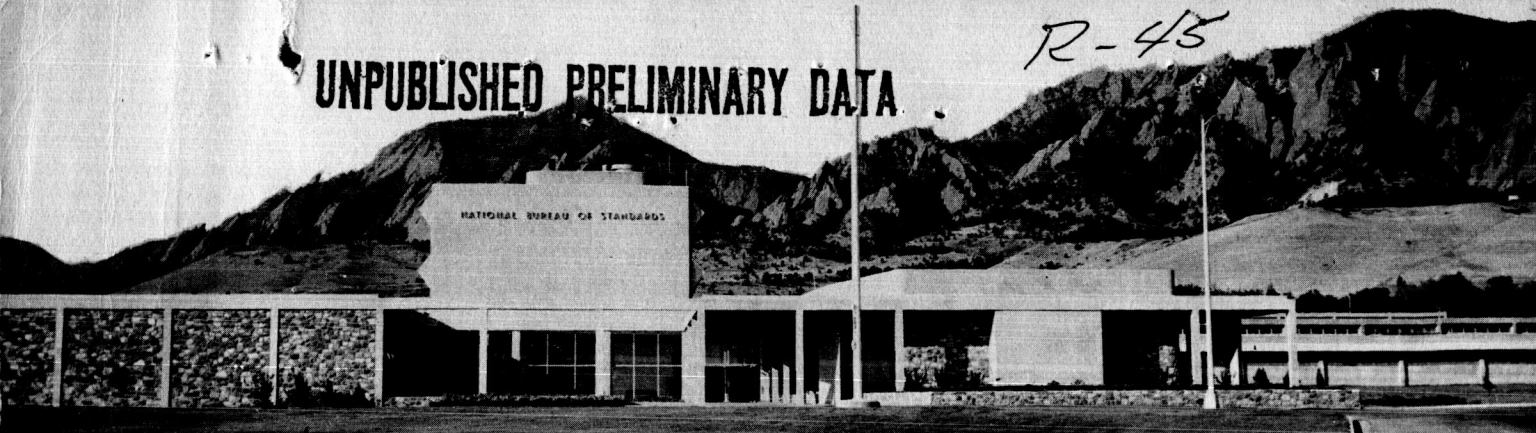


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ELEVENTH PROGRESS REPORT

to

National Aeronautics and Space Administration

on

2; Cryogenic Research and Development

for

Period Ending September 30, 1963

Progress Report No. 11.

all copies

(NASA Contract R-45)

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# NATIONAL BUREAU OF STANDARDS REPORT

## NBS PROJECT

8120-14-81410  
8120-40-81420  
8120-12-81421  
8120-40-81520  
8150-40-81550

September 30, 1963

## NBS REPORT

7979

### ELEVENTH PROGRESS REPORT

to

National Aeronautics and Space Administration

on

Cryogenic Research and Development

for

Period Ending September 30, 1963

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## 1. Physical Properties of Cryogenic Fluids

### 1.1 Thermodynamic and Transport Properties

R. D. Goodwin, D. E. Diller, H. M. Roder, L. A. Weber and B. A. Younglove

Current status is summarized by table 81550. New publications during this reporting period are listed under "Publications". The tedious work continues, of developing completely smooth and self-consistent tables of thermodynamic and derived properties of parahydrogen. Some apparently useful progress has been made in the search for a relatively simple equation of state for parahydrogen at high densities. Experimental viscosity technique is being refined to obtain higher precision, while sonic velocity measurements at cryogenic temperatures will begin in October 1963.

Special apparatus and instrumentation for conducting P-V-T measurements on oxygen is about 50% completed.

### 1.2 Dielectric Constant

John W. Stewart

The dielectric constant of liquid and gaseous parahydrogen has been measured by the capacitance ratio method from 24° to 100°K and from 2 to 326 atmospheres. This encompasses the density range 0.002 - 0.080 g cm<sup>-3</sup>. These data have been combined with the P-V-T data of Goodwin and co-workers to calculate the Clausius-Mossotti function

$$P = \frac{1}{\rho} \frac{\epsilon - 1}{\epsilon + 2}$$

where  $\epsilon$  is dielectric constant, and  $\rho$  is density. The precision of P

is about 0.05%. All previous determinations of  $P$  for hydrogen have been of too low precision to demonstrate that  $P$  was anything but constant regardless of temperature and density. On the other hand the present investigation shows  $P$  rising with density to a maximum about 0.2% above the zero-density value at about  $\rho = .040 \text{ g cm}^{-3}$  and then decreasing. Behavior of this general nature is predicted on theoretical grounds and has been observed in precise measurements of a few other simple fluids ( $\text{Ar}$ ,  $\text{CO}_2$ ). The data suggest a slight dependence of  $P$  on  $T$ , but this was within the experimental accuracy and cannot be considered to be definitely established. Assuming  $P$  to be independent of  $T$ , the results are well represented by the relation

$$1/P = A + B\rho + C\rho^2$$

$$A = 0.99575 \pm 0.00131$$

$$B = -0.09069 \pm 0.0246$$

$$C = 1.1227 \pm 0.289$$

using cm - g units. At zero density  $P$  is  $1.00427 \text{ cm}^3 \text{ g}^{-1}$ . The range of values for  $P$  is  $1.005 \pm 0.001$  in agreement with the mean value of  $1.01 \pm 0.01$  adopted earlier by Corruccini in NBS Tech. Note 144 (April, 1962). The dielectric constant can be calculated at any desired density up to  $0.080 \text{ g cm}^{-3}$  from the above equation and the Calusius-Mossotti equation rearranged to

$$\epsilon = \frac{1 + 2\rho P}{1 - \rho P}$$

A manuscript describing this research is being prepared. This work was supported by NBS.

### Publications

(Papers and Reports published under the NASA Contract, that have become available during the current reporting period).

1.       The Correlation of Experimental Pressure-Density-Temperature and Specific Heat Data for Parahydrogen, by H. M. Roder, L. A. Weber and R. D. Goodwin. Internat. Inst. duu Froid, Comm. 1, I-6, (1963).
2.       A Comparison of Two Melting-Pressure Equations Constrained to the Triple Point Using Data for Eleven Gasses and Three Metals, by R. D. Goodwin and L. A. Weber, NBS Tech. Note 183, (1963).
3.       Second and Third Virial Coefficients for Hydrogen, by R. D. Goodwin, D. E. Diller, H. M. Roder and L. A. Weber, submitted to J. Res. NBS (Section A) in September, 1963.
4.       Survey of Current NBS Work on Properties of Parahydrogen, R. D. Goodwin, Wm. J. Hall, H. M. Roder, L. A. Weber, and B. A. Younglove, accepted June 10, 1963 for publication in Volume 9 of Advances in Cryogenic Engineering, K. D. Timmerhaus, Editor.

## 2. Cryogenic Metrology (Instrumentation)

### 2.0 General Comments

Personnel contributing to this activity during the reporting period were: T. M. Flynn, W. J. Alspach, M. D. Bunch, D. A. Burgeson, C. E. Miller, and R. J. Richards.

Two publications, one invited paper, and three conference seminars resulting from this task appeared during the reporting period:

D. A. Burgeson, W. G. Pestalozzi, and R. J. Richards, "The Performance of Point Level Sensors in Liquid Hydrogen", Adv. in Cry. Eng., 9 (in press).

R. C. Muhlenhaupt, and P. Smelser, "Carbon Resistors for Cryogenic Liquid Level Measurement", NBS Technical Note No. 200 (Sept. 1963).

T. M. Flynn, "Instrumentation for Low Temperatures", Invited paper, D-5, 1963 Cryogenic Engineering Conference, August 19-21, 1963, Boulder, Colorado (unpublished).

T. M. Flynn, "Mass Flowmetering", Tutorial Seminar, S-3, 1963 Cryogenic Engineering Conference, August 19-21, 1963, Boulder, Colorado (unpublished, held three times in seminar fashion).

### 2.1 Temperature Transducer Test Program

Since the review of the test program revealed a need for the investigation of several effects which influence fundamental measurements with temperature transducers, the prime effort during this quarter has been to organize an evaluation program. Design of the

necessary apparatus and organization of the experimental test procedure is now in progress.

A calibration apparatus is planned to measure all fundamental temperature coefficients at equilibrium conditions. The new time-temperature response apparatus is in fabrication and will be used to study the dynamic characteristics of temperature transducers. This apparatus should be operational during the next quarter.

A survey of temperature instrumentation is in progress for experimental studies of the selected error inducing parameters. The parameters to be studied here are those adverse effects caused by mechanical vibration, external pressure, installation-application, and environmental variations. A detailed analysis of the composite data will allow a classification of all transducers.

Review of the mathematical time response model is in progress with the purpose of determining the extent of its validity. The next quarter should decide whether revisions are necessary, or a new analysis should be made.

## 2.2 Pressure Transducer Test Program

The carbon resistor pressure transducer test series reported in the 9th Quarterly Report (NBS Report No. 7921) has been continued along three lines: (a) investigation of creep, or long term stability, (b) determination of the gage factor, and (c) determination of the most advantageous stressing technique. The results are incomplete, and accordingly are not reported at this time.

Attention has been focused on continuing the evaluation of commercial pressure transducers, similar to that work reported in the 5th and 6th Quarterly Reports (NBS Reports Nos. 7246 and 7279). The goal of this program is to establish guidelines for the selection and application of pressure transducers. The program will comprise

three parts: (a) research on the basic phenomena that may be applied to cryogenic pressure measurements, (b) evaluations of commercial pressure transducers on a common basis, and (c) investigation of application techniques as they influence the value and response of the pressure measurement.

## 2.3 Liquid Level Transducer Program

### 2.3.1 Transducer Testing

The testing program was continued with the following sensors: Minneapolis Honeywell thermistor, Glennite thermistor, Cryresco carbon resistor, United Control hot wire, and four General Dynamics/Astronautics hot wires. The tests have been completed with liquid hydrogen, liquid nitrogen and water. Simmonds thermistor was included in the liquid nitrogen and water tests only. The data have been reduced for the liquid hydrogen and liquid nitrogen tests, and the curves have been plotted for the hydrogen tests. Comparison of the transducer function in the three fluids will be made.

Pressure levels for the tests on hydrogen were the same as previous tests - for nitrogen 2, 20, 35, and 50 psig, and the water tests were run at ambient pressure.

### 2.3.2 Reports

The continued testing plus the quantity of data to be reduced and plotted have delayed the completion of final report on liquid level point sensor testing to the sponsor.

A summary of the liquid level test work to date was compiled in an abbreviated report entitled "The Performance of Point Level Sensors in Liquid Hydrogen". This report was presented on August 21, 1963 at the Cryogenic Engineering Conference in Boulder, Colorado. Copies of the report have been submitted to the sponsor and

are available in reprint form from the Cryogenic Engineering Laboratory Data Center. The paper will also appear in "Advances in Cryogenic Engineering" 9, (1963) in press.

#### 2.4 Density and Quality Measurement

A thorough literature search has been completed, and evaluation of the field is in progress. This analysis will provide the basis for investigation of the fundamental principles of cryogenic fluid density and quality measurements.

Many interesting techniques of quality measurement appear useful, provided that a sample of vapor only, or liquid only, can be made. That is, most quality measuring techniques have in common a measurement of the total sample, and a reference measurement of one phase alone. Accordingly, two devices basic to quality studies have been designed and constructed: (a) a mixing chamber, designed to produce any degree of quality in the total sample; and (b) a separator, designed to separate the liquid and vapor portions of a mixed flowing sample.

The forced vibration densitometer, reported in the January issue of the Review of Scientific Instruments, has been analyzed for possible modification for hydrogen service. The device appears to be suitable for hydrogen use, with a few obvious design and material changes. Such modifications and testing in hydrogen are under review.

One very promising density measuring technique has been investigated during this quarter, and is reported in detail in the following section, No. 2.5.



## 2.5 Flow Measurement

### 2.5.1 NMR Flow Measurement Technique

The possibility of using the nuclear magnetic resonance technique for liquid hydrogen mass flow measurement is being investigated. This technique is, in essence, a particle counting method. As such, it should be feasible for mass flow measurement of liquids, gases, or a mixture of liquids and gases. No moving mechanical parts are necessary in the flow stream. A search of the literature revealed that only a small amount of work has been done using this technique for flow measurement, and that very little has been done with cryogenics. This technique is particularly suited to cryogenics, which are single component, simple molecular systems of high purity.

A description of the nuclear magnetic resonance technique follows:

It has been known for some time that many nuclei possess a nuclear spin. Nuclear spin is a characteristic of all nuclei which have unpaired protons such as the hydrogen and nitrogen nuclei.

From quantum mechanics, it can be shown that spinning nuclei, when placed in a dc magnetic field, align themselves in a definite manner with respect to the magnetic field. The particular position which the momentum vector takes depends on several factors, one of which is its nuclear structure (i. e., the number of protons and neutrons), and the energy state of the nuclei. The capability of changing the direction of the momentum vector by supplying energy in the form of rf waves permits the observation of a number of characteristics peculiar to the specimen.

Consider the case of the hydrogen nuclei. This nuclei, having one proton, has a spin  $I = 1/2$ , where  $(2I + 1)$  indicates the number of energy states that a nuclei can possess. From quantum mechanics,

it can be shown that the momentum vector can take  $(2I + 1)$  values in the series:

$$(I), (I-1), (I-2), \dots, -(I-1), -(I).$$

Thus, the hydrogen proton may take two states, aligned either parallel or anti-parallel to the magnetic field. The number of nuclei in excess of those which remain parallel (lower energy state) is referred to as the excess number of spins,  $N_o$ . When the spin and lattice are in thermal equilibrium and in a steady state magnetic field, the excess number of spins is given by the expression:

$$N_o = \frac{N \mu H_o}{k T} \quad (1)$$

where:

$$\begin{aligned} N &= \text{total number of nuclei per cm}^3 \\ \mu &= \text{magnetic moment} \\ H_o &= \text{steady state magnetic field} \\ k &= \text{Boltzman's constant} \\ T &= \text{temperature of fluid} \end{aligned}$$

When an rf field is impressed upon the above system, the excess nuclei will be reduced to a final steady state value  $N_s$ .

$$\begin{aligned} N_s &= (N_o) \left( \frac{1}{1 + 2 p T_1} \right) \\ &= \frac{N}{T} \left[ \frac{\mu H_o}{K} \left( \frac{1}{1 + 2 p T_1} \right) \right] \end{aligned} \quad (2)$$

where:

$$T_1 = \text{spin lattice relaxation time}$$

$P$  = probability per unit time of a transition by the nuclei  
under the influence of the rf field.

From (2), it follows that the density of the fluid is proportional to the excess nuclei when the fluid is in the saturated condition, and directly proportional to the absolute temperature or:

$$\rho \propto N_s \cdot T.$$

The quantum of energy necessary to excite transition between the energy states (hydrogen having two energy states) is given by the following equation:

$$h = \frac{g \mu H_o}{f_o} \quad (3)$$

where:

$g$  = splitting factor (constant)

$f_o$  = frequency of rf field

Thus, if a sample of hydrogen is placed in a dc magnetic field for a sufficient length of time to align the nuclei, and then a suddenly applied magnetic field, at a frequency in accordance with (3) is directed normal to the plane of the dc steady state field, the nuclei which were aligned anti-parallel to the field will reverse their spin vector by  $180^\circ$ . In so doing, they will give up a quantum of energy. Similarly, those nuclei which were aligned parallel (lower energy state) will be supplied with an equal quantum of energy. If there were no excess protons in the lower energy state there would be no net absorption of energy. Since excess protons do exist, there will be a net transfer of energy supplied by the rf field. A measure of this energy provides a means of determining fluid density.

Figure 2-1 indicates a system which can be used to determine velocities of moving fluids. In the presence of an rf field, the number of excess spins,  $N_o$ , at any time is given by the first order ordinary differential equation:

$$\frac{dN_o}{dt} = \frac{N_o - N}{T_1} - 2 N p \quad (4)$$

The complete solution of (4) for the system shown in Figure 2-1 is:

$$\frac{N}{N_o} \lambda = 1 + \frac{T_1 V}{\ell} \left[ \left( \frac{1}{\lambda} - 1 \right) + \exp \left( - \frac{d_1}{V T_1} \right) \right] \left[ \exp \left( - \frac{\lambda \ell}{V T_1} - 1 \right) \right] \quad (5)$$

This equation (5) describes the observed phenomena over the entire range of fluid velocities. When the velocity is small relative to  $d_1/T_1$  and  $\lambda \ell/T_1$ , where  $\lambda = 1 + 2 p T_1$ , the equation reduces to:

$$V = \frac{N_o d_1}{N T_1} \quad (6)$$

An additional technique that may be used to determine fluid velocity is the tracer technique as indicated in Figure 2-2.

Fluid flowing in the line is in the dc magnetic ( $H_o$ ) for a period of time sufficient to align the nuclei. Coil 1 is periodically energized at a frequency and strength sufficient to cause transition of the excess

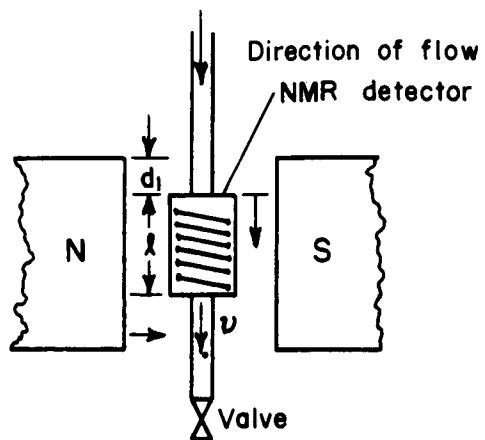


Figure 2-1

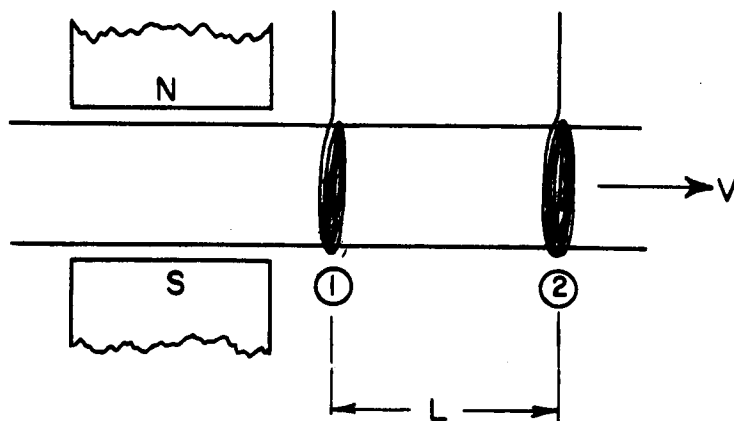


Figure 2-2

protons. A second coil, mounted at a distance (L) downstream from coil 1, detects the differential volume as it passes through the coil. A measure of the time required for the differential volume to move from coil 1 to coil 2 is a measure of fluid velocity. With a knowledge of fluid velocity and the constant area of the flow line, fluid volume flow is determined.

Mass flow rate can be determined using known electronic means to multiply the fluid density signals and the fluid volume flow signal.

To date, flow measurements using the NMR technique have been performed using water as a fluid. The tests were conducted at the University of Colorado Physics Department. Results of such a water flow test are shown in figure 2-3 , a plot of output signal versus fluid volume flow.

The water flow measurement test apparatus is shown in Figure 2-4. Figure 2-5 shows a block diagram of the electronic equipment used for measuring the NMR signal.

The test consisted of flowing water through a small diameter non-conducting tube placed between the pole faces of an electro-magnet. A coil was wound around the outer diameter of the non-conducting tube. Water flow rate was measured by weighing a discrete amount of water and measuring the length of time required to flow this amount of water. Various flow rates were established by this method.

Future work concerning the NMR technique for flow measurement will be to:

1. Continue investigation of the density-temperature effects using water as a fluid.
2. Examine the effects of varying ortho-para concentration of liquid hydrogen.
3. Assemble a complete electronic system.

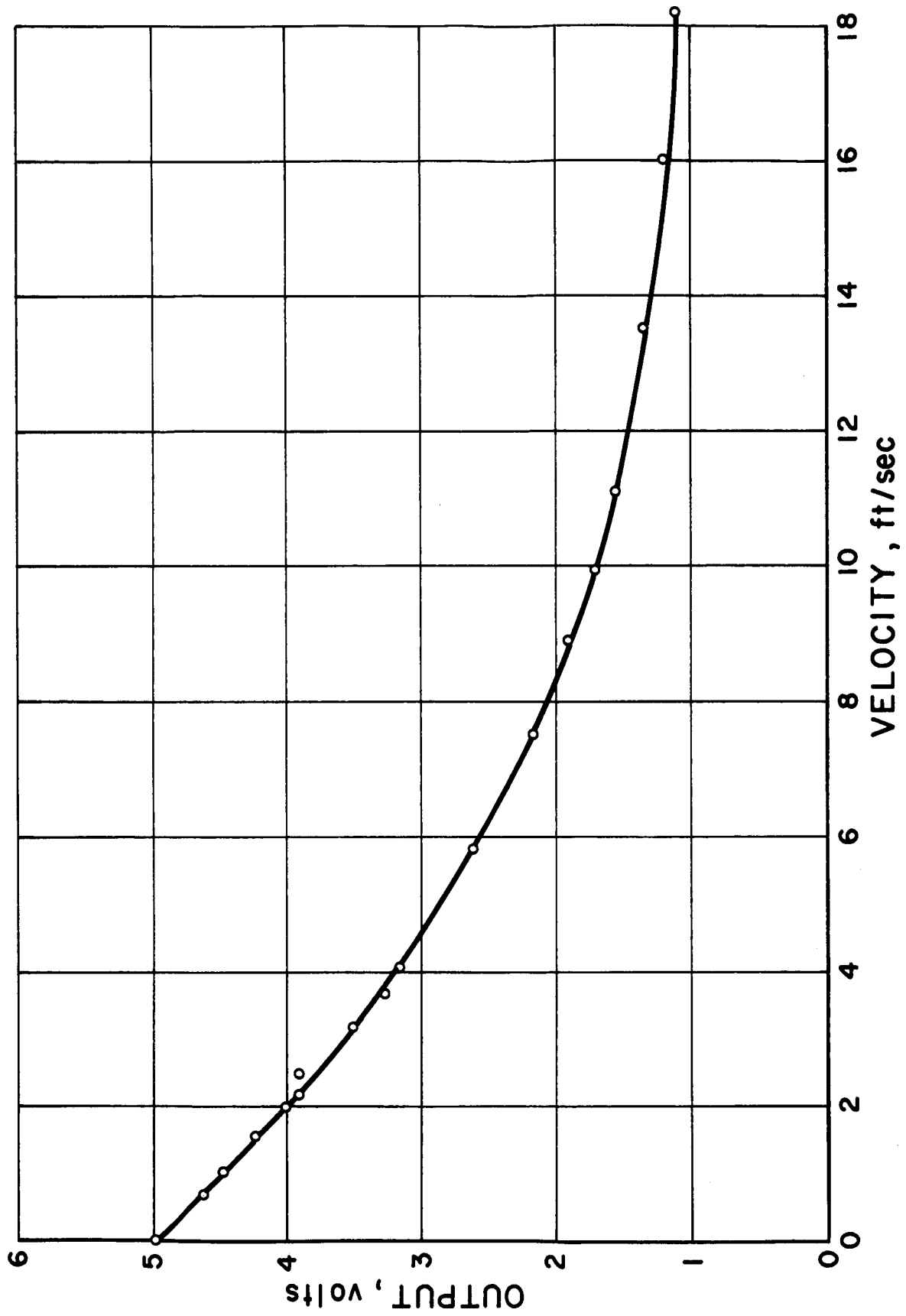


Figure 2-3

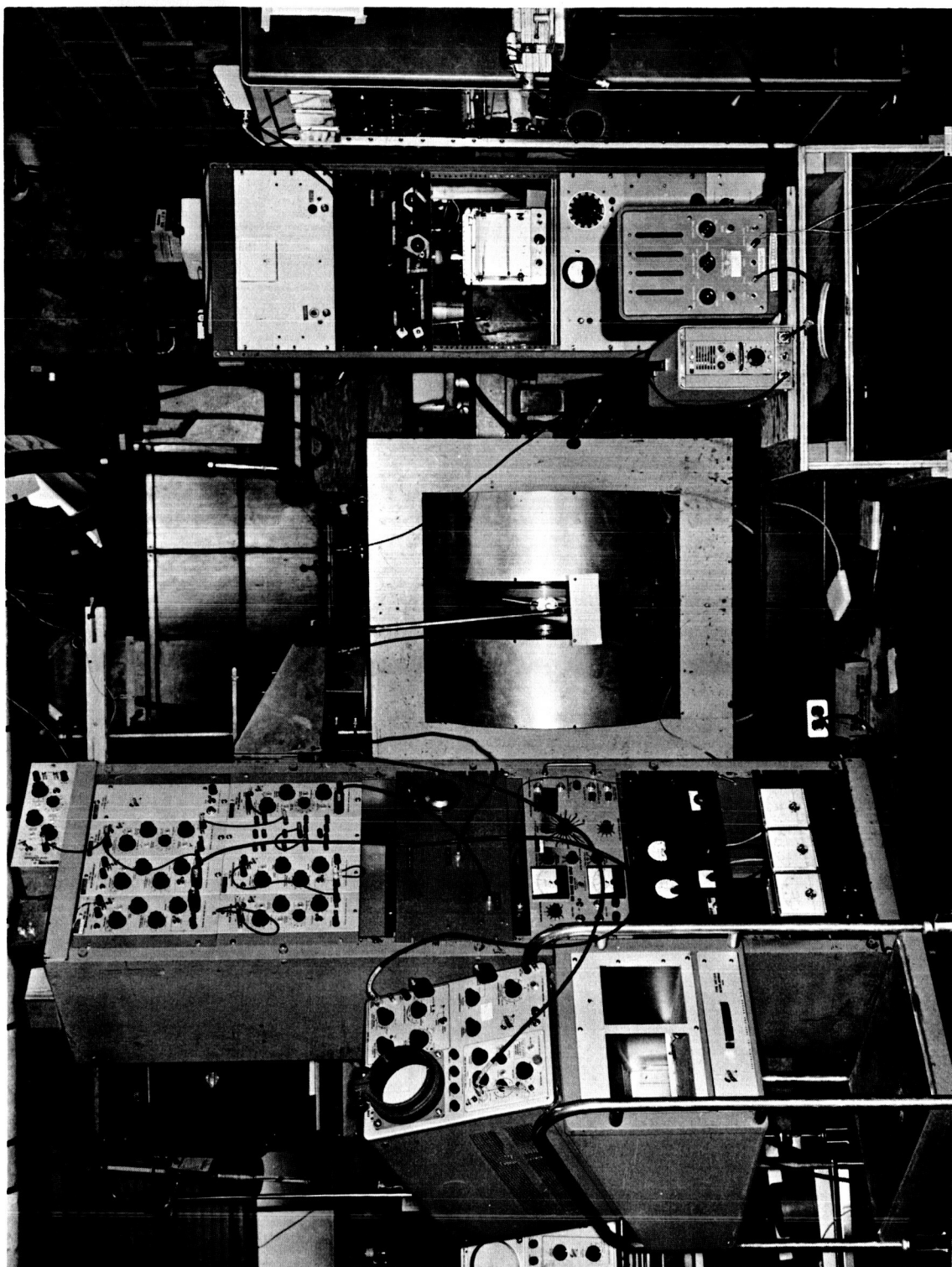
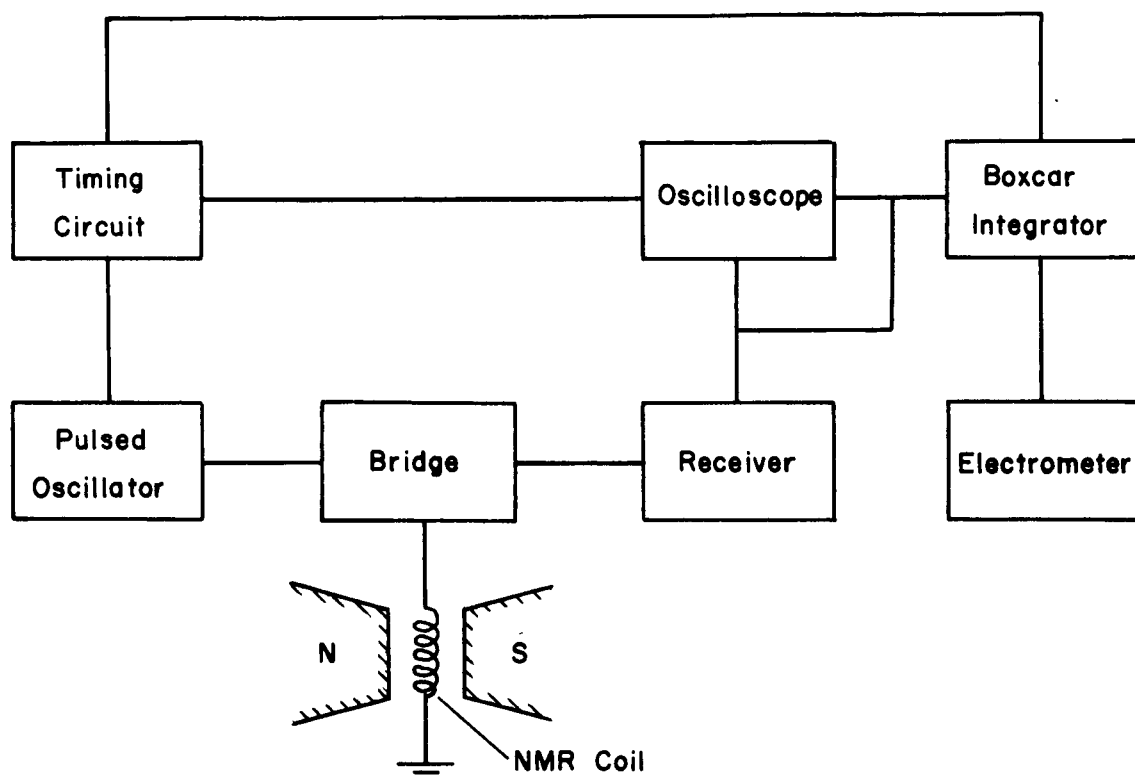


Figure 2-4. NMR Test Apparatus





NMR Electronic System  
Figure 2-5

4. Investigate field strength-length of magnet field parameters.
5. Conduct a small scale liquid hydrogen flow test.

#### 2. 5. 2 Flowmetering Survey

On September 10, 1963 the Cryogenic Flowmeter Survey forms were mailed out to 142 different sources. Of these sources, 42 were classed as possible cryogenic flowmeter users, 90 were classed as possible cryogenic flowmeter manufacturers, and 10 were universities or institutes.

During the next quarter reminder letters will be sent to those sources who have not yet returned the form. Compilation of the survey results will also be started.

#### 2. 5. 3 Flowmetering Assistance

During the past quarter, assistance on cryogenic flow measurement was given to General Dynamics/Astronautics concerning the measurement of hydrogen boil off for the Centaur hydrogen tankage. A meeting with representatives of Waugh-Foxboro, cryogenic flowmeter manufacturers, was also held at Boulder on the subject of liquid hydrogen flowmetering and calibration.

#### 2. 6 NERVA Instrumentation

In July, a meeting was held at SNPO-C to plan and initiate the NBS participation in the NERVA cryogenic instrumentation program. Objectives were defined and interface problems resolved. It was decided to survey and assist SNPO-C in the evaluation of the NERVA cryogenic instrumentation program. Specific research to assist this program will be planned and conducted. This effort will entail work that is dependent upon and in addition to the broad cryogenic metrology tasks, and will be closely coordinated with those tasks.

The implementation of this task during this past quarter has comprised:

1. The Instrumentation Data Book, AGC Report No. 2320, has been reviewed for format, program, progress, plans and measurement requirements. This report appears to be a good systematic approach for compiling a great quantity of data, as well as being a program management instrument. A few points deserving attention have been reported to SNPO-C. This review shall continue as new issues arrive.

2. The Instrumentation Data Book (IDB) format has been adopted for reporting our own investigations, to permit ready intercomparison.

3. Wherever possible, the specific instruments listed in the IDB shall be selected for evaluation in our regular program.

4. An NBS representative attended the Instrumentation, Data Acquisition, and Data Reduction Review meeting for NRX-A at SNPO-C in August. The meeting was sponsored jointly by SNPO-C, WANL, and the REON Division of Aerojet-General Corporation to review the NRX-A Block 1 Instrumentation, Data Acquisition and Data Reduction Systems. The agenda was based upon the Aerojet-General document, "AGC Report No. 2320, Instrumentation Data Book."

We were invited by SNPO-C to participate in the review of the measurement requirements, problem items, availability, accuracy, synergistic environment, etc. Prospects for successful solutions to the problem areas of transducers of pressure, temperature, strain, displacement, and flow were discussed.

5. Trips are planned to AGC-LRP, WANL, and NRDS to discuss the experimental and development programs, and to exchange information during the next quarter.

## 2.7 Literature Survey

A literature survey of cryogenic instrumentation was started during this quarter. At the end of the reporting period over 900 citations had been compiled. Only about 10% of these had abstracts. The process of abstracting the remainder will be a task distributed to the staff for completion in specific areas of interest.

Much consideration has been given to the system of literature retrieval. At this writing, the system presenting capabilities most desirable to the needs of cryogenic instrumentation and measurement is the "peek-a-boo" punched card system.

The "peek-a-boo" system is described in R. S. Casey et al "Punched Cards", second edition, chapter 6, pp 125-151, Reinhold Publishing Corp. 1958.

The choice of this system has been based on its expandibility, previous use by NBS in the field of instrumentation, simplicity of system and compatibility with existing and proposed cryogenic data center systems. It will be relatively inexpensive to photographically reproduce any of the index cards, abstracts, or hard copy on microfilm for distribution if future requirements indicate a need for this type of system.

## 2.8 Analog Simulation

A large portion of our analysis is dependent upon the solution of field problems involving functions of several variables. Examples are found in the temperature response of complete cryogenic thermometer systems, and the frequency response of pressure transducers.

Classical solutions become excessively difficult for these examples where initial and boundary conditions are anything except the most simple cases or when simplifying assumptions are not justified.

Some of the more complex initial and boundary conditions may be handled by classical methods with a transformation of coordinates, but the engineer soon loses physical contact with the problem when a solution is performed in an abstract mathematical domain. The general purpose analog computer has the advantage of being able to electrically simulate the problem in its original physical domain. Initial conditions are applied as reference voltages and boundary conditions of considerable complexity may be applied by the use of the computer's non-linear components.

In cases where classical solutions may be obtained and automated, the digital computer will remain the more powerful tool because of its better precision. When classical solutions are not obtainable, numerical techniques may be applied on the digital computer. This leads to discretized lumped parameter mathematical models consisting of simultaneous finite difference algebraic equations that are sometimes solvable by matrix algebra techniques. Difficulties often arise with solution convergency and stability. The analog computer when used for a similar type of analysis partially avoids these problems by not having to discretize the time derivative. The analog may be used to rapidly change the problem parameters by changing potentiometer settings while observing the solution form on an oscilloscope and thus determine areas of problem stability and convergency. If the analog solution is not sufficiently precise, the solution may then be run with assurance on the digital machine. Thus the analog should be used in support of, and not in lieu of, the digital machine.

The analog is particularly adept at solving differential equations that have only one independent variable. The general purpose analog computer, although no panacea, will be a useful tool for differential analysis.

A ten-node R-C analog computer network has been constructed to provide transient solutions to the Fourier heat transfer equation. This simulator has been useful in analyzing the time response of temperature sensors. General purpose commercial analog computers are being investigated for suitability to other instrumentation problems.

## 2.9 Contractor Liaison

### 2.9.1 Visitors to NBS-CELD

Messrs. D. G. Phillips, NASA-RASPO, North American Aviation, Downey, California, and K. J. Corpening, NAA Space and Information Division, Downey, California, visited NBS-CELD on July 31, 1963. The purpose of the visit was to ascertain methods of determining purity of liquid hydrogen and liquid oxygen to be used for the Appolo space capsule fuel cell and life support systems.

The 99.95 percent minimum purity specification requires verification instrumentation and cleanliness procedures not yet available either commercially or on a laboratory basis. Based on this visit, Messrs. Phillips and Corpening were to initiate funding to investigate contamination caused from transfer line sources.

Mr. Billie Bray of NASA-Marshall, M-Test-M1 (Vitro Services), Huntsville, Alabama, visited from September 16 through September 20, 1963 for the purpose of calibrating a hydrogen gas flowmeter. This work was performed on a purchase order basis, although such calibrations are not ordinarily performed here.

### 2.9.2 NBS Visits to Other Facilities and NASA-Lewis Research Center

Trips made during this period in support of the NASA cryogenic instrumentation were as follows:

1) A trip to the A. D. Little Company (July 14, 15, 1963) was made to complete the liquid hydrogen point sensor report for the Cryogenic Engineering Conference (see Paragraph 2.3.2) and to make arrangements to include some of A. D. Little's test work in the NBS final report to sponsor.

2) One trip was made to General Dynamics/Astronautics, San Diego, California on "Centaur" instrumentation of the "Cryo Tower" August 15, 16, 1963 (See Section 3.1 also).

3) One trip was made to NASA-Lewis Research Center, Cleveland, Ohio on September 10, 11, 1963 to discuss cryogenic thermometry problems associated with "Centaur" (See Section 3.1 also).

4) Two trips to NASA-SNPO-C, Cleveland, Ohio were made on July 8 through 10 and August 12 through 14, 1963, for the purpose of consultation on "NERVA" cryogenic engineering.

### 3. Consultation and Advisory Services

D. B. Chelton

Consultation and advisory services in the general field of cryogenic engineering has continued in two NASA program areas; Project Centaur (funded separately) and Projects Rover and Nerva. On the latter two, particular emphasis has been placed on the Nerva phase.

#### 3.1 Project Centaur

General assistance was given to NASA, Lewis Research Center and General Dynamics/Astronautics (GD/A) in several areas, some of which were of a minor nature and will not be discussed in detail. Specific areas in which a relatively concentrated effort was placed are discussed below. All tasks pursued under the project have been performed at the request and agreement of NASA, Lewis Research Center. Active coordination of our efforts has been essential for maximum utilization.

Meetings were attended at GD/A regarding the Propellant Level Indicating System (PLIS). Consultation was provided on a review of the test facilities for calibration of the PLIS on the proposed "cryo" tower. The program and analysis was presented by GD/A and is presently under further consideration.

Considerable emphasis was placed upon the measurement of skin temperature under conditions simulating the environment of AC-4 during flight. A test apparatus was constructed to provide a 20°K surface, a high vacuum environment ( $10^{-6}$  mm Hg) and various rates of incident thermal radiation to selected temperature measuring devices. The apparatus was later modified to allow the determination of system response to an abrupt change of surface temperature.



To date, three specific platinum resistance thermometer (PRT) designs and two germanium thermometers have been included in our experiments. The apparent temperatures compared to a known temperature and the system response times have been determined and verbally reported to NASA and GD/A.

A vital part of the program has been to determine a method of thermometer attachment to provide good thermal contact and to have sufficient strength to withstand the relatively high strain of the Centaur vehicle (estimated at 0.005 inch/inch). Several methods of attachment were strained in a tensile cryostat to provide information. This portion of the effort is to be concluded in the near future.

It is emphasized that the above program determined system characteristics which includes the method of attachment; thermometer characteristics alone are not sufficient for our purposes. A final report on our investigation will be prepared in the near future. Results of our experiments were disseminated as they were generated.

A more intensive effort, aimed at providing assistance to GD/A and NASA on problems which had arisen with the rate of self pressurization in the Centaur AC-2 tank and the related thermal stratification of the liquid was started. Advisory and consultative services were furnished together with a study of experimental results and analytical treatments available from the literature.

Meetings were held with GD/A and NASA personnel to discuss the relatively high pressure rise rates experienced in tests up to that time and the plans for a program to simulate low-g orbital conditions. It was pointed out that extrapolation of the 1-g test data obtained from a small scale container to the low-g, full scale flight container presented a major problem. It was urged that additional instrumentation should be included on a flight test.

On September 21, October 3, and October 9, pressure rise rate tests at the Point Loma facility of GD/A were observed and recommendations made for modifications to the test procedures. These tests were designed and monitored by the Pneumatics and Thermodynamics groups at GD/A. They were the first tests conducted with flight type insulation on the forward bulkhead and designed specifically to provide information concerning the pressure rise rate and the thermal stratification problems. Final reduction of the test data is not complete, but preliminary results show the pressure rise rate to be approximately 3.5 psi/min.; well below the 7 to 10 psi/min. rates previously obtained. A significant limitation of the Point Loma test facility is the lack of adequate temperature print-out equipment.

Further study is being conducted on an analytical method of predicting pressure rise rates and thermal stratification, with special emphasis on the effect of low-g conditions.

To fulfill all of the above tasks, a total of seven trips were made to GD/A and two trips to NASA, Lewis Research Center. In addition, several visits were made by personnel of the above organizations to NBS.

### 3.2 Project Rover

General assistance was given to the Los Alamos Scientific Laboratory (LASL) in several areas of cryogenic interest. These included the subjects of ground support equipment and mechanical properties of solid materials. The total quantity of effort was relatively low in order that Nerva considerations could be concentrated upon.

### 3.3 Project Nerva

As a result of preliminary contacts with SNPO personnel, our participation in the Nerva program, as presently conceived, will be concentrated in the area of fluid phenomena. Our considerations will be limited to cryogenic portions of the nuclear engine under development by the Astronuclear Laboratory of Westinghouse Electric Corporation. Pertinent documents have been forwarded to us and are under review at the present time. Included in our program area will be the review of test apparatus, procedures and data generated in the course of experimentation. Consideration will also be given to the review of specifications, drawings and plans for cryogenic equipment as required.

Necessary AEC security clearances have been filed to bring the project to full complement and so that we may call upon other key members of the staff as necessary to accomplish project objectives.

## 4. The Compilation of Thermophysical Properties of Cryogenic Materials

R. B. Stewart and V. J. Johnson

This project is engaged in the evaluation and compilation of thermophysical property data from the technical literature. Tables and graphs of data based on "best values" selected from the literature are compiled for wide ranges of temperature and pressure. A summary of the tasks in progress during the current reporting period follows:

### 4.1 Thermodynamic Properties of the Cryogenic Fluids

The task for the compilation of thermodynamic property data for neon has been essentially completed. A paper reviewing some of this

work was presented to the Cryogenic Engineering Conference in August, 1963. The report included temperature-entropy charts from 25 to 80°K and 60 to 300°K. A study of the inversion curve for neon is now in progress. Although the results of this study are as yet inconclusive, the uncertainties of the projected thermodynamic properties at high pressure may be greater than originally estimated. This question should be resolved in the next few weeks. An NBS Technical Note is now in progress to summarize the work on the task for compiling thermodynamic properties for neon. This Technical Note will include extensive tables of the thermodynamic properties.

The P-V-T data for oxygen, both liquid and gaseous, has been evaluated and fitted to an equation of state for the generation of tables and the calculation of thermodynamic properties. A preliminary table of thermodynamic property data for oxygen has been prepared and issued as NBS Report 7922 which is now available from the Cryogenic Data Center. Additional experimental data are now being reviewed in an attempt to reconcile this data with the P-V-T values.

The task for compilation of thermodynamic property data for carbon monoxide has been completed. The results of this work have been published as NBS Technical Note 202. This publication includes P-Z and T-S charts from 70 to 300°K with pressures to 300 atmospheres and extensive tabulations of the thermodynamic properties.

The P-V-T data for argon, both liquid and gaseous, has been evaluated and fitted to an equation of state for the generation of tables and the calculation of thermodynamic properties. Thermodynamic property tables for argon have been calculated and will be issued in a preliminary form in an NBS report. This report will make these tables available for use while further evaluations are in progress.

The task for the compilation of the saturation properties (vapor pressure, saturation densities, latent heats and specific heats at constant saturation - for all phase transitions) is being continued.

The construction of T-S and H-S diagrams for helium has been undertaken. These charts will cover the range 3 - 300°K and 0.5 to 100 atm. The data source for these charts is NBS Technical Note 154. Two T-S charts have already been completed for 3-25°K and 15 - 300°K, and are now being checked for accuracy.

The task for the compilation of the specific heat data for the cryogenic fluids has been undertaken. The initial objective is the compilation of the experimental data from the literature.

In addition to the paper noted above on the thermodynamic properties of neon, two additional papers will be published in the proceedings of the 1963 Cryogenic Engineering Conference, which have resulted from the activities of this project. The first is entitled "A Correlation of Thermodynamic Properties of Cryogenic Fluids" and is a review of the thermodynamic property compilation effort in the Cryogenic Data Center. The second paper entitled "Functions for the Calculation of Entropy, Enthalpy, and Internal Energy for Real Fluids Using Equations of State and Specific Heats" presents derivations of the equations for the calculation of thermodynamic property tabulations. Preprints of these papers are available from the Cryogenic Data Center.

#### 4.2 Additional Thermophysical Properties for Cryogenic Materials

The task for compiling the electrical resistivity data for the pure metallic elements is essentially completed. Data sheets will be compiled for each of the elements considered in this compilation. This

work is being pursued at a low priority.

No progress has been made during the current reporting period in the task for compiling surface tension and dielectric constant data.

#### 4.3 Bibliographies of selected topics

The task of compiling a bibliography of literature containing the experimental data of saturation properties of cryogenic fluids is continuing. Approximately, five hundred references have been accumulated which report experimental data on this subject. Approximately, 80% of these documents have been coded for content and indexed. The literature search for this project is essentially completed and the task of preparing the manuscript of citations has been undertaken.

The task for preparing a bibliography on the thermophysical properties of argon is continuing. The literature search for this project is essentially completed. Approximately 350 references have been obtained and coded. The manuscript for the bibliography is now being prepared.

A continuing awareness of the current scientific literature is being maintained in conjunction with Cryogenic Data Center Documentation Unit. Copies of documents related to present and future tasks for the Evaluation Unit are being obtained and indexed. Additional bibliographies on selected topics resulting from this activity will be published periodically.

#### 4.4 Summary charts

Summary charts of all tasks under this project follow on the next two pages.

#### 4.4 Summary Chart, Project 81440

### THERMODYNAMIC PROPERTIES OF CRYOGENIC FLUIDS

	Helium	Neon	Oxygen	Argon	Carbon Monoxide	Para-hydrogen	Nitrogen	Helium
Priority Currently Assigned*	0	1/4	1	1/4	0	0	0	1/4
Pressure Range (atm. )	0.1 to 100	0.1 to 200	0.1 to 300	0.1 to 1000	0.1 to 300	1 to 340	0.1 to 200	0.5 to 100
Temperature Range (°K)	20 to 300	25 to 300	55 to 300	86 to 300	70 to 300	20 to 300	65 to 300	3 to 300
Phases Included**	1	1, 2, 4, 5	1, 2, 4, 5	1, 2, 4, 5	1, 2, 4, 5	1, 2, 4, 5	1, 2, 4, 5	1, 2, 4, 5
Literature Searched, Summarized	X	X	X	X	X			
Experimental Data Compiled	X	X	X	X	X			
Data Evaluated, Best Values Selected	X	X	X	X	X			
Equation of State Determined	X	X	X	X	X			
Tables of P-ρ-T Values Determined	X	X	X	X	X			
Tables of Entropy, Enthalpy Calculated	X	X	(Preliminary)	IP	X			
P-Z Diagram Constructed	X	X			X			
T-S (H-S) Diagram Constructed	X	X			X	X	X	IP
Report Manuscript in Progress		X		X				
Report Published	X		(Preliminary)		X			

\*Fraction indicates portion of time devoted to task by one full-time professional staff member

\*\*1 - gas  
2 - liquid  
3 - solid

4 - saturated gas  
5 - saturated liquid  
6 - saturated solid

IP = in progress

4.4 Summary Chart, Project 81440 (continued)

ADDITIONAL THERMOPHYSICAL PROPERTIES

Priority Currently Assigned*	Surface Tension	Dielectric Constant	Electrical Resistivity	Saturation Properties	Specific Heats
Materials Included	1/4	1/4	1/10	1/4	1/4
Phases Included**	Cryogenic Fluids	Cryogenic Fluids	Pure Metals	Cryogenic Fluids	Cryogenic Fluids
Temperature Range (°K)	5	1, 2, 3	3	4, 5, 6	1, 2, 3
Literature Searched, Summarized	t. p to c. p	undecided	0 to 300 °K		
Experimental Data Compiled	X	X	X	IP	IP
Data Evaluated, Best Values Selected	X	X	X	IP	IP
Analytic Equation Determined	IP				
Tables of Values Determined					
Property Diagram Constructed					
Report Manuscript in Progress	IP	IP	IP	IP	
Report Published					

BIBLIOGRAPHIES

Priority*	Literature Search Completed	Documents Coded	Manuscript in Progress	Report Published
0	X	X		X
0	X	X		X
1/2	X	X	X	
0	X	X		X
1/4	X	IP	X	

\*Fraction indicates portion of time devoted to task by one full-time professional staff member.

\*\*1 - gas  
2 - liquid  
3 - solid  
4 - saturated gas  
5 - saturated liquid  
6 - saturated solid

IP = in progress



## 5.0 Research on Cooldown of Cryogenic Transfer Lines

### 5.1 Experimental and Semi-Empirical Studies

W. G. Steward and W. H. Probert

The cooldown experimental apparatus was reassembled and checked out with liquid nitrogen. The pressure and temperature instruments functioned properly; however, the flow meter showed signs of having accumulated moisture during the year of disuse. The flow meter signal was restored, and the apparatus is now ready to use. The test schedule will depend largely on the availability of the recording equipment and amplifiers which must be shared with other projects.

A report on the cooldown time analysis was completed and is now being reviewed. The pressure surge analysis has been expanded to include the effects of variable inlet temperature. Computed results are shown for comparison with the experimental data in Figure 1. Two extremes of inlet temperature are shown. The higher values are for an inlet liquid at ambient boiling temperature, the lower values are for the maximum possible inlet temperature, i. e., liquid saturated at the driving pressure. Judgment of the value of the analysis is being reserved until further comparisons with experiments are possible.

In the coming quarter the emphasis will be toward obtaining the necessary experimental data to fully evaluate the analytical results.

### 5.2 Theoretical Studies

S. Jarvis

Application of the Courant-Isaacson-Rees finite difference method for numerical integration of a hyperbolic system approximating the flow in the two-phase cooldown problem when coupled with further

restrictions based on sources, has resulted in a stable computing scheme capable of handling large changes in the flow variables with a rather large mesh size. The scheme is weakest when derivatives are small, due to the dominance of diffusion-like terms which give the scheme stability. In the cooldown problem, this has manifested itself in the absence of a second surge and the approach to a quasi-steady state.

The introduction of some non-linear factors into the diffusion terms appears very promising as a method for eliminating this difficulty, and should be theoretically sound if the result is not strongly dependent on the nature of these factors.

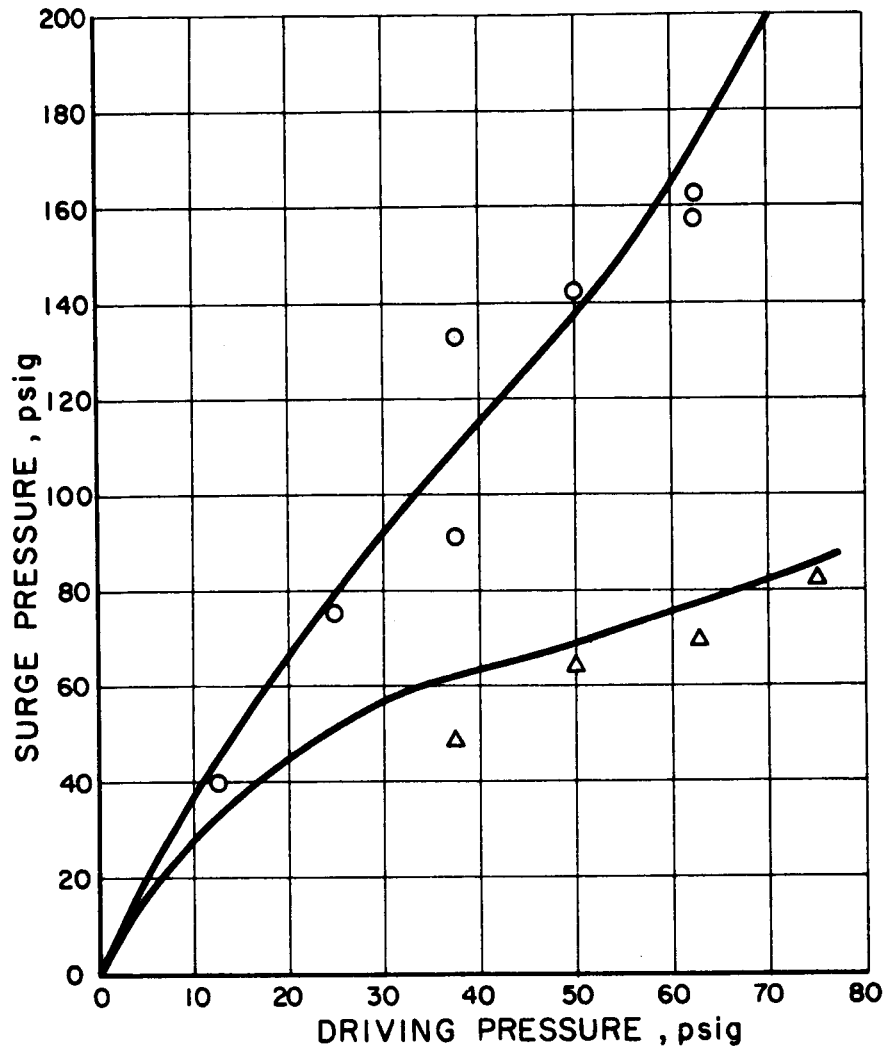


Figure 1. Surge pressure for liquid nitrogen entering a 200 ft. long, 5/8 in. inside diameter transfer line. The upper computed line and experimental points are for a liquid inlet temperature of 75.7 deg. K (ambient boiling temperature); the lower line and points are for inlet liquid saturated at the driving pressure.